Chapter 4: Water in the Main Injector

> The study of water is such a dry subject that nothing funny can be said about it; there is no such thing as aqueous humor.

The magnets, power supplies, and RF systems in the Main Injector use tremendous amounts of power, and the heat generated from these components must somehow be removed. The Low Conductivity Water (LCW) systems provide cooling to the devices that need it. At each of the major service buildings, about 2.5 MW of power is dissipated as heat; a total of up to 8,000 gallons a minute passes through the components to keep them cool.

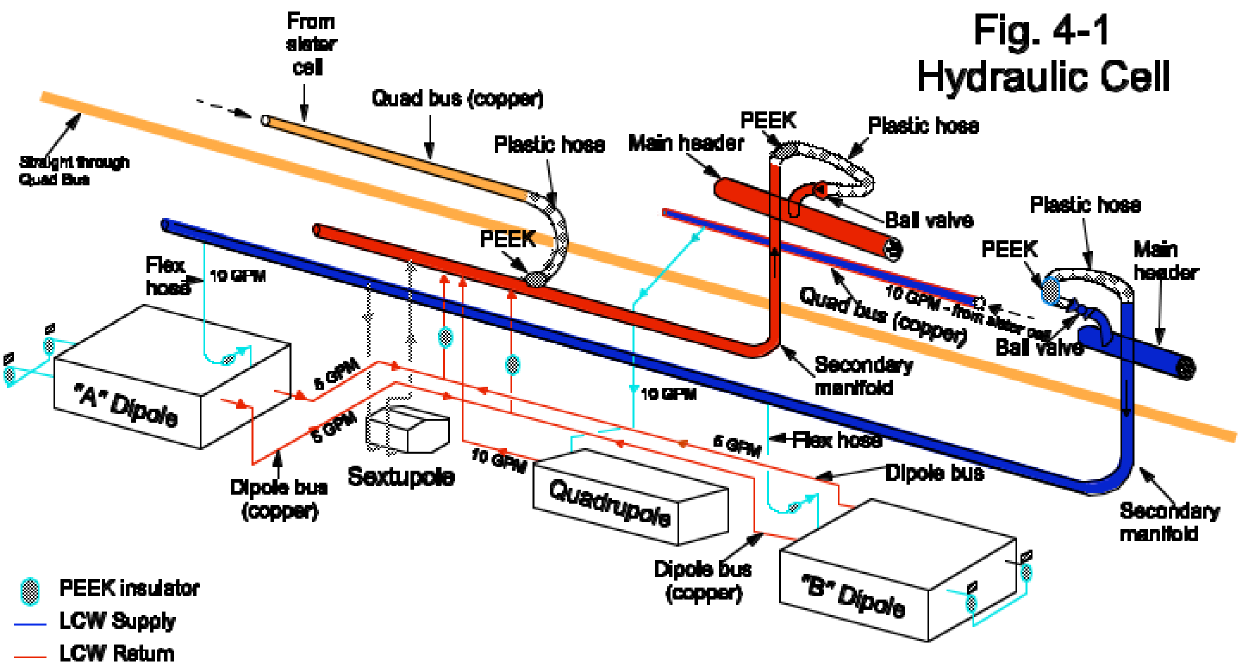
"Low conductivity" is essential because the water circulates directly through electrical conductors, such as the copper coils inside the magnets. The high voltages applied to the magnets would cause ions dissolved in the water to migrate and create currents of their own, disrupting the performance of the magnets and possibly causing damage.

The LCW system can be appreciated at several levels. It is important to understand how the water is distributed to the magnets in the tunnel, as well as the power supplies upstairs. Pumping, cooling, and deionization of the LCW all occur in the service buildings. The water required to cool the LCW is circulated in ponds distributed around the Main Injector ring. Finally, there are controls to coordinate the system.

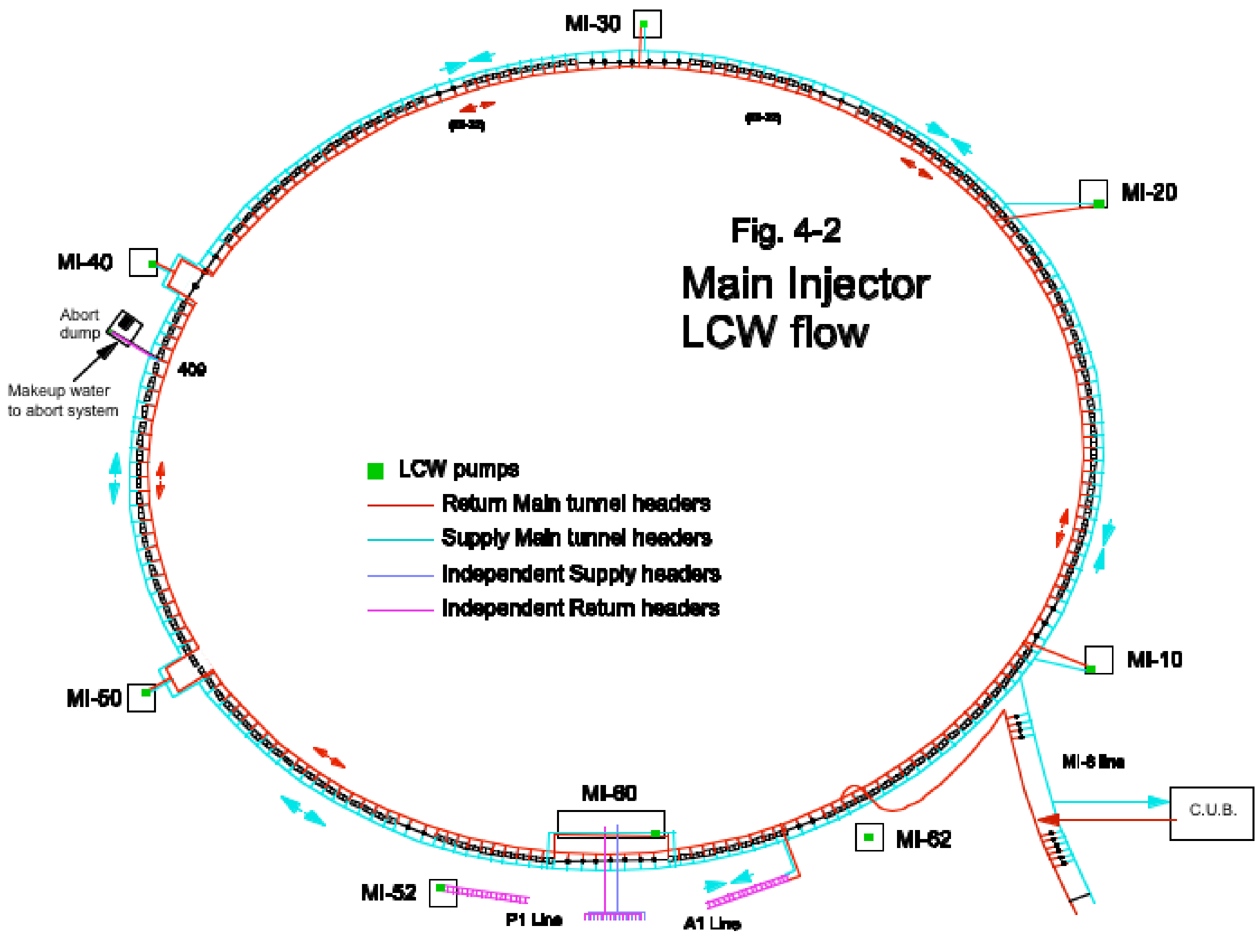
This chapter is concerned primarily with water systems in the ring, as well as the supporting role played by the Central Utility Building (CUB). Detailed discussion of systems specific to the beam lines (e.g. the abort, P1, and A1 lines) is deferred to the chapter on Beam Transport Lines.

LCW in the Tunnel

Two stainless steel pipes, running the length of the tunnel between service buildings, distribute LCW to the magnets (Fig. 4-1, 4-2). One of the 6” diameter pipes is known as the supply header because it supplies cool water to the magnets; the other pipe, which collects the warm water emerging from the magnets, is the return header. The supply pressure, the pressure of the water in the supply header, is about 185 psig. The return pressure is about 15 to 20 psig. (Incidentally, psig stands for “pounds per square inch gauge.” Pressure gauges are often calibrated to read zero pounds at atmospheric pressure, so a pressure reading in psig should be interpreted to represent pounds per square inch above atmospheric pressure.) The difference between the supply and return pressures forces the water through the magnets.



Secondary manifolds branch from the main LCW header at each main quadrupole location, supplying water to the main dipoles and main quadrupoles. The sextupoles are not water cooled at present. The ball valves on the main headers isolate the dipoles, but the quadrupoles must be isolated with valves on the quadrupole bus (not shown here). Compare to Fig. 4-2; the quadrupole shown here could be Q630. Her sisters would be Q628 (supply) and Q632 (return).



Because the LCW is going to pass through electrically active components, the stainless steel headers must be electrically isolated from the magnets. All of the hoses connecting the water pipes to the magnets are equipped with PEEK insulators to prevent the magnets from being grounded through the pipes. ("PEEK" stands for "polyether ether ketone." Unfortunately, it is also a completely unrelated trade name found on some of the LCW metering electronics.) PEEK is a relatively hard and inflexible substance used where sturdiness is required; plastic hoses of non-PEEK composition are also used where it is anticipated that thermal expansion and contraction of the pipes could cause problems. There are specialized cases where ceramic insulators are used as well. All of the insulators allow continuity of water flow, but block electrical current. The water itself will not conduct significant amounts of current because most of the ions have been removed.

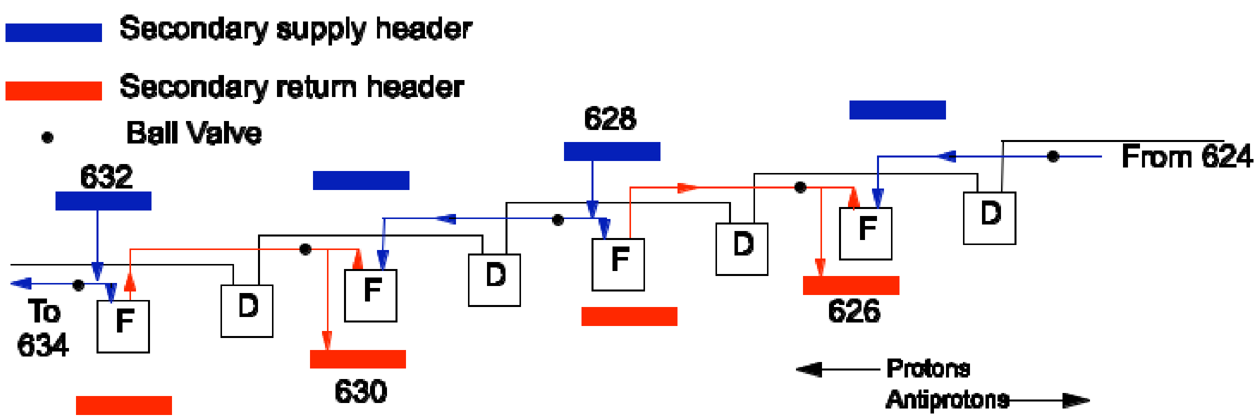
The magnets in the tunnel that dissipate enough heat to require water-cooling are the main dipoles and main quadrupoles. The other, smaller magnets are air-cooled, although provisions have been made to supply water to the sextupoles should it become necessary. The cooling units are organized into hydraulic cells, which consist of a main quadrupole and the two main dipoles to either side. The boundaries of the hydraulic cells do not correspond to those of the cells of the FODO lattice.

At each hydraulic cell, LCW is distributed to the individual magnets through secondary manifolds. There are supply and return manifolds at each cell. Ball valves are present which can be used to isolate the main headers from their respective secondary manifolds in the event of a leak or scheduled maintenance.

A line carrying 10 gallons per minute (GPM) runs to each of the two main dipoles from the supply manifold; PEEK insulators electrically isolate the magnets from the manifold. The water enters the magnets through a connection at the top, on the side facing the main quadrupole. Inside the magnet, the flow splits into two branches. Water passes through the holes in the copper coils (Fig. 2-2); in order to cool the upper and lower coils as well as the straight-through bus, the flow turns around at the opposite end of the magnets and makes a second pass through. The jumpers are provided with PEEK insulators so that the magnet is not electrically shorted.

The 1” X 4” main dipole bus which runs behind the quadrupole must also be cooled, so water returning from the magnets passes through the bus on its way back to the return manifold.

Water to the quadrupoles is handled differently for historical reasons. Many of the quadrupoles have been recycled from the Main Ring, where the LCW was carried inside the copper bus. For consistency, the new quadrupoles have been built in the same manner. The quadrupole bus is a hollow copper pipe; the copper carries the power and the LCW flows inside the pipe. At the secondary manifold, the quad bus is connected to either the supply or return manifold through a plastic hose. Consider the focusing bus (Fig. 4-3). At a given location, the bus may be connected to, say, the supply manifold. Since this particular length of bus is connected to two focusing quadrupoles, the flow is divided between the two magnets. For example, the supply header at Q628 also supplies Q630. The quad bus at the next focusing location (in either direction) is connected to the return manifold. For example, Q630 is connected to the return manifold, which also collects warm water from Q632. Two hydraulic cells tied together via the quadrupole bus are called "sister cells."



At each main quadrupole location, the magnet is alternately connected to either the supply header or the return header. Since every magnet needs access to both a supply and a return header, each secondary header must be connected to two quadrupoles (compare to Fig. 4-1). Also, since the water travels through the buss work, the two "sister" magnets must have the same polarity. Ball valves are used to isolate the quadrupoles from the main header.

This picture, for the sake of clarity, only shows connections to focusing quads.

Fig. 4-3, Sister Cells

The defocusing bus follows the same pattern, but is one half-cell "out of phase" with the focusing bus.

A careful look at Figs. 4-1 and 4-3 reveals that closing the ball valves to the secondary headers is insufficient to isolate the quadrupole magnets, because LCW can still flow in from a sister cell. If a leak develops at a quad, there are small (3/4") ball valves upstream and downstream, on the quadrupole bus itself, which must also be closed. The upstream valve is almost a half-cell away, while the downstream valve is nearly a full cell away.

The valves are adjacent to breaks in the bus that have been jumpered with braided copper cabling to allow for thermal expansion of the pipe.

Since the 6” supply and return headers are present around the entire circumference of the ring, and since LCW passes from the supply header through the magnets to the return header at several hundred locations, the ring-wide view can be thought of as a large capillary network with the components being cooled in parallel. In Fig. 4-2, each “crossover” in the ring from the supply to the return header represents a secondary manifold. At the service buildings, warm return water from the magnets is drawn upstairs, where it is cooled, deionized and pressurized before being sent back into the tunnel as supply water.

Notice that water is sent out from the service buildings in both the upstream and downstream directions, and returns from both directions. At some point along the route, as water is drawn from the supply header, the pressure from adjacent service buildings will be equal. To ensure that the water will not completely stagnate, there are flow restrictors on the headers for adjusting the differential pressures. They are located in the service buildings, just before the headers enter the tunnel, and are set up to induce a slow net flow in a clockwise direction.

Occasionally, the headers branch out to cover specialized functions. LCW supply water is shunted to CUB from a point between 640 and 641, eventually coming back to the return line at 624. A short branch at MI-40 supplies the Abort Lambertsons. At 409, water is siphoned off for the quasi-independent LCW system of the abort dump. The abort water heat exchanges with the ring LCW, and makeup water is supplied from the main headers, but the abort LCW is a closed-loop system with its own deionizer. Between 618 and 619 there is a branch from the main header that supplies water to devices in the A1 (or A150) line.

In addition, there are three LCW systems completely independent from the rest. At MI-52, there is a closed-loop system that supplies LCW to the devices in the P1 (or P150) line. Water is pumped from the MI-52 Service

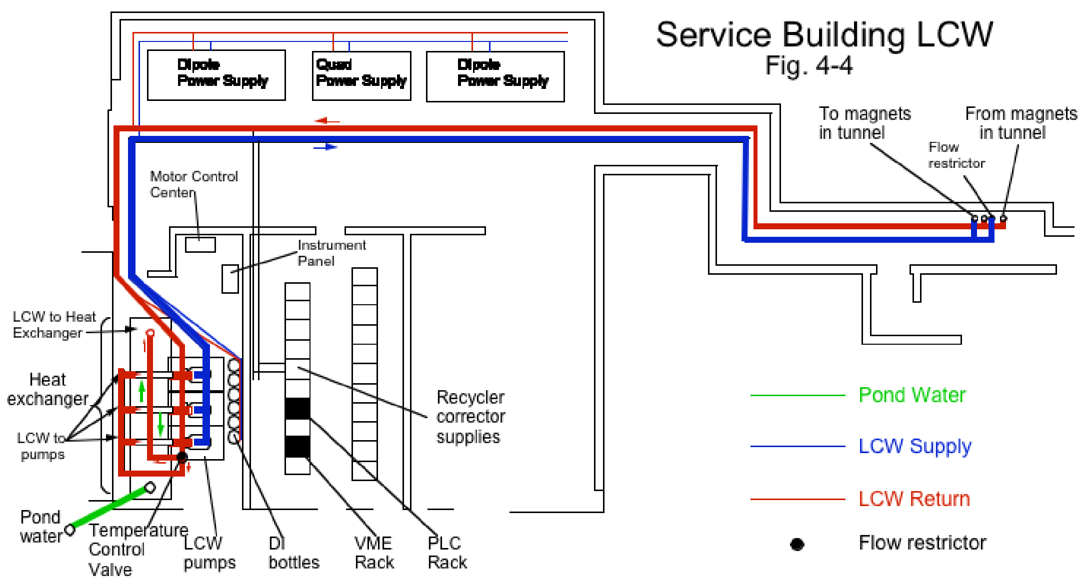
Building; the headers run along the inside wall of the tunnel before crossing over to the magnets at 523.

More detail on the abort, P1, and A1 LCW systems will be included in the “Beam Transport Lines” chapter.

The other two independent systems are at MI-60. (This would be a good time to begin pondering Fig. 4-7, but don’t sweat the details yet.) One system known as the “RF” or “95°” system, supplies water to the RF electronics upstairs, the RF amplifiers downstairs, and to the anode supplies. The other, known as the “Cavity” (or quite inaccurately, the “55°” system) provides water to the RF cavities downstairs. The RF and Cavity LCW systems will be dealt with in a separate section.

LCW in the Service Buildings

Each service building houses equipment dedicated to maintaining the LCW under its regional sphere of influence (Fig. 4-4). The layout is similar from house to house (except at MI-60, which will be discussed later).



At the service buildings, cool LCW is pumped to the magnets in the tunnel and the power supplies upstairs. The main headers are suspended from the ceiling.

Only the external plumbing of the heat exchanger is shown here; this diagram should be compared to the cross-section in the text. The warm LCW returns to the Temperature Control Valve (TCV), to the right of the exchanger in this diagram. (The header is not connected to any of the structures shown beneath it.) The valve splits the LCW into two branches. The branch in the center is heat exchanged with pond water from outside (the pond water is represented somewhat schematically). The other branch bypasses the exchanger. The two flows are then combined (not shown). Finally, the combined flow is divided into three branches, which pass under the exchanger to the LCW pumps.

The hardware includes LCW pumps, a heat exchanger, and deionization tanks.

In addition to the figures in this book, the graphics on page I56 will be helpful in understanding the details discussed for the remainder of this chapter.

LCW Pumps

The pumps are the heart of the LCW system, providing the differential pressure necessary to keep the water circulating in the ring and through the magnets. Each of the 100 horsepower pumps is capable of receiving LCW at a pressure of 15 or 20 psig from the return header and pressurizing it to about 185 psig as it enters the supply header. All three pumps are normally running at any given time; about a thousand gallons of water is pumped to the magnets in the tunnel from each service building every minute.

Low-pressure water in the return line before it enters the pump is called suction, and the high-pressure water leaving the pump is referred to as discharge.

The motors for the LCW pumps are powered and controlled from panels in the Motor Control Center (MCC). The pumps each have a dedicated panel on the MCC from which they can be turned on and off. For remote control of the pumps, the MCC is the interface with the controls system.

The supply and return headers work their way out of the pump room, past the main power supplies; the penetrations into the tunnel are located next to the door leading into the tunnel. Notice in Fig. 4-4 that the supply and return headers each split into two branches just before entering the tunnel; one runs upstream of the service building and the other downstream (compare to Fig. 4-3). The flow restrictors are located on one of the branches of the supply header.

Cooling for the main dipole and main quadrupole power supplies is tapped from the main headers that branch of the LCW runs behind the power supply cabinets. There are manually operated supply and return valves for isolating each of the three supplies. In addition, a small branch taps off the main headers to feed the Recycler corrector supplies in the electronics room.

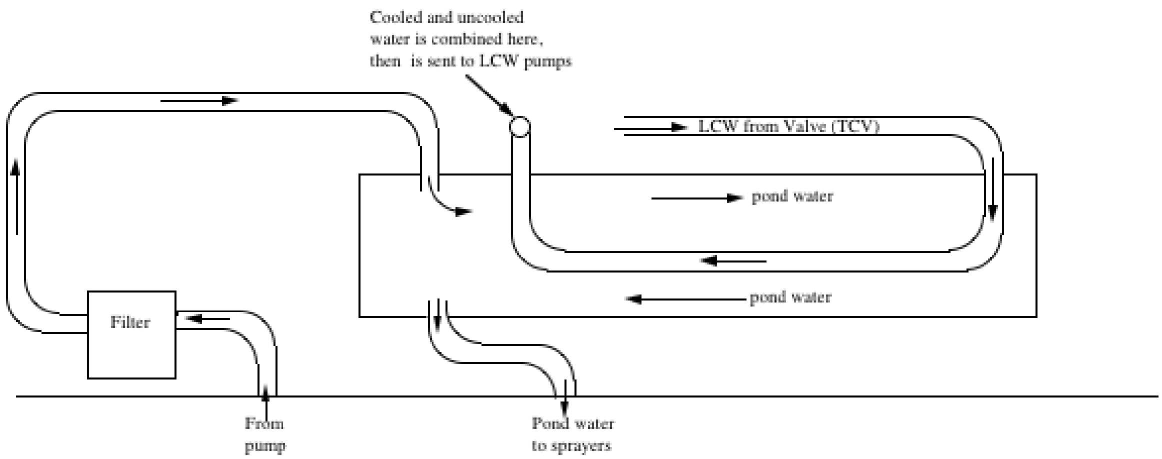
Heat Exchangers

The return flow to the pumps takes a somewhat convoluted path as it approaches the heat exchanger. The heat exchangers, one in each building, cool the water returning from the magnets. Some of the warm LCW passes through a pipe that runs the length of the exchanger, while cool water from outdoor ponds flows past the pipe. Although the two bodies of water do not actually meet, heat is transferred from the warm LCW to the cooler pond water, as in the diagram on the next page.

Before encountering the heat exchanger, water returning from the tunnel and power supplies enters the Temperature Control Valve (TCV), also known as the 3-way valve. The TCV splits the flow between a branch that passes through the heat exchanger, and a branch that does not. The ratio of cooled to warm water determines the temperature of the water that will be sent to the magnets. The valve is given a setting temperature, usually around 90˚ F, and continuously adjusts the ratio in order to maintain that temperature. The readback is set up so that “% open” refers to the percentage of the return flow sent to the heat exchanger.

In Fig. 4-4, in which only the external plumbing of the heat exchanger is represented, the return flow can be seen splitting into the two branches. The branch seen directly over the heat exchanger enters the exchanger at the far end and flows back through the inner pipe. The other branch bypasses the exchanger altogether. The two flows merge at the point indicated (the inner pipe leaving the heat exchanger is hidden in this view). Finally, the combined flow splits one more time to feed all three of the LCW pumps.

The cool pond water from the pond pumps comes up through the floor, passes through a large filter, and enters the heat exchanger at the top. It flows the length of the exchanger, first passing over the LCW pipe and then, on the return path, underneath. It leaves the bottom of the heat exchanger and returns underground to the outside sprayers. A more global view of the pond pumps is forthcoming.



Cross-Section of Heat Exchnager

Deionization

A small portion of the discharge from the LCW pumps is sent through a series of deionizer (DI) bottles. The bottles are just fancy (and very thorough) water softeners that remove dissolved ions from the water. The DI bottles are filled with tiny resin particles that have been treated to retain an electric charge. These "mixed bed" deionizers are comprised of negatively and positively charged resins. Ions in the water, such as calcium, magnesium, sodium, sulfate, bicarbonate, etc., are captured by the particles. When the resins become saturated with ions, they must be flushed with caustic substances in order to recharge them.

Non-ionic nuisances, such as copper oxides, are immune to capture by the resins.

The optimal flow through recharged deionizer bottles is about 40 GPM, but that rate slows down as the resins become saturated. The bottles need to maintain a flow of at least 5 GPM in order to function properly.

To protect the deionizers, there is a regulator upstream of the bottles which steps the pressure down from the 185 psig of the supply line to about 50 psig.

The conductivity of the water is usually measured in units of its antithesis, resistivity. Resistivity is expressed in ohms per centimeter. The greater the resistivity, the cleaner the water. LCW in the Main Injector should be in the neighborhood of at least 8 Megohms (millions of ohms) per cm, and can be as high as 18 Megohms per cm.

As a backup, there are filters at the beginning and end of the series of bottles that clean the water and offer some protection to the rest of the system in the event that a bottle goes bad.

Ponds and Pond Pumps

The cooling ponds ultimately dissipate heat from the magnets and power supplies. These elongated ponds are adjacent to the berm, sometimes to the outside of the ring and sometimes to the inside (Fig. 4-5). Designated A through H, they have a total of about 19 acres for evaporative cooling. It turns out that the rate of evaporation is the most important factor limiting the ramp rate of the ring.

The pond water is not low conductivity, it would be rather difficult to maintain ion-free water in an open outdoor environment.

There are two pond pumps at the downstream end of each pond that pump water out of the pond and into the service buildings to be heat exchanged with the LCW. Usually, only one pump is running at a time at any given service building. After absorbing heat from the LCW, pond water is usually pumped to the upstream side of the adjacent pond through sprayers. Water in a spray will cool faster because of the increased surface area of the droplets. (The spraying nozzles are removed in the winter to prevent the roads from icing over on windy days.) The pond water before it is heat exchanged is defined as supply water; after the heat exchanger it is referred to as return water.

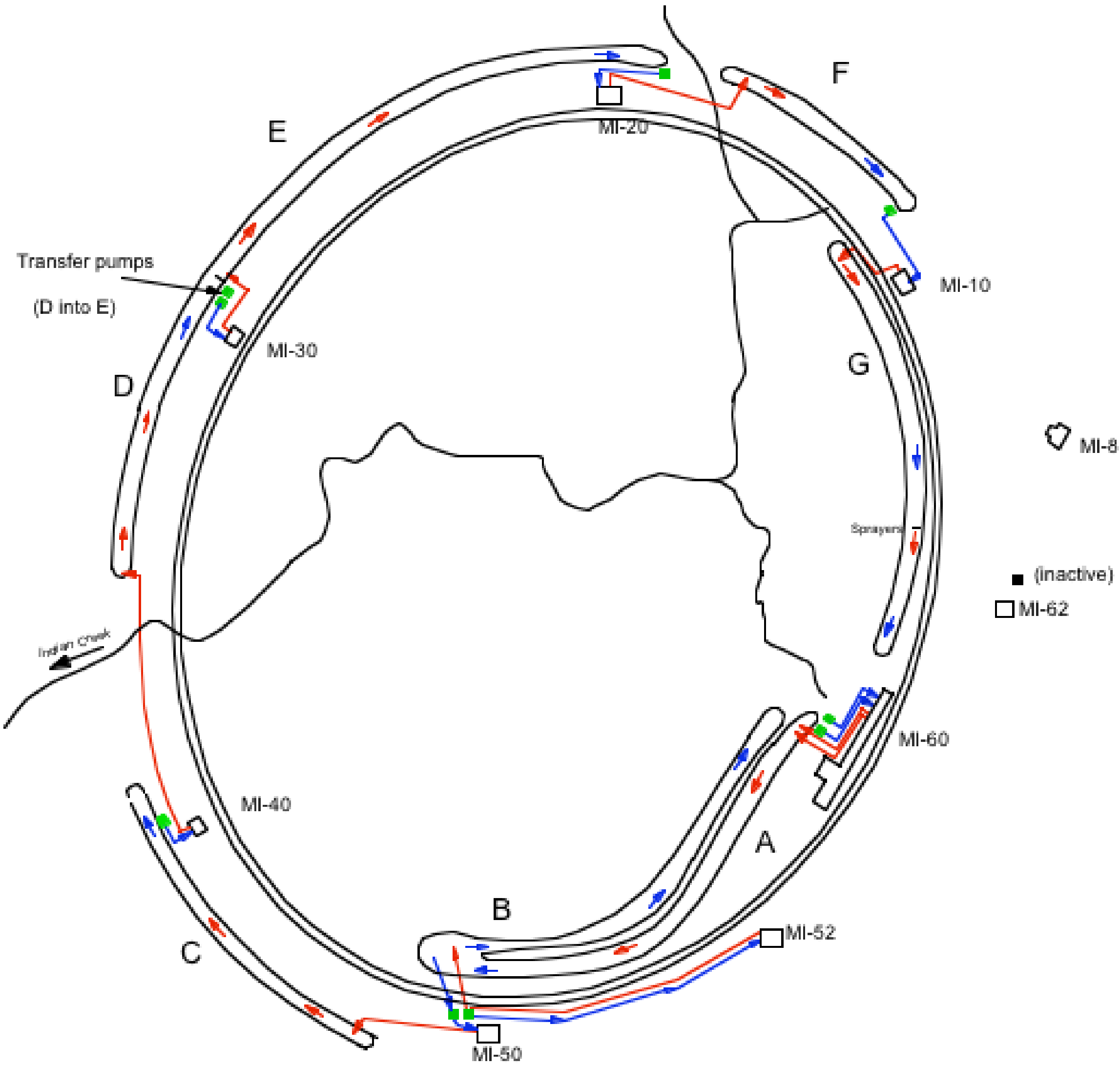


Fig. 4-5 Pond Water Circulation

Cool water is drawn from the ponds and used in the heat exchangers to cool the LCW returning from the magnets. The warm water from the heat exchangers is returned to the ponds via sprayers, and allowed to cool by evaporation. Each green square represents a pair of pumps.

The inactive pumps near MI-62 will probably be used when the A1 and NuMI lines are commissioned.

The location of the pumps is designed so that there is (in general) a constant clockwise flow around the ring. After warm water is discharged at the upstream end of a pond, it slowly drifts downstream and cools by evaporation. At the downstream end of the pond, it is cool enough to be used as supply water for the next service building.

Sometimes there is a significant distance between ponds, as between C and D (so that Indian Creek can run between them), and sometimes only a dam separates the ponds. The A and B ponds are continuous, as are G and H, but are given distinct names because there are pumping stations midway through.

The MI-52 LCW system, which is independent of the ring system, sends its warm pond water to the point where the “A” pond turns around, behind the MI-50 Service Building. It draws cool water from a point upstream of the discharge.

In addition to the usual pumps, there is a “lift pump” at MI-30. Rather than being tied into a heat exchanger, its sole purpose is to transfer water from one pond to another in order to maintain the proper levels.

The pond pumps are housed in concrete pits but can be susceptible to flooding. Sump pumps in the pits prevent the pond pumps from being submerged. When the pit fills to a certain level, the sump pump discharges the water back into the pond.

Local LCW Controls

The local LCW controls at a service building must be able to read the various pressure, temperature, flow, and conductivity values, as well as pump and valve status. They must also be able to execute commands such as turning the pumps on or off, and regulating water temperature through the TCV. Finally, all of this information must be shuttled back and forth between the service building and the Main Control Room (see Fig. 4-6 on the next page).

Most of the instrumentation reports to modules in the Instrument Panel, located in the pump room. The equipment in the Instrument Panel is more of a collection than an integrated system, and the individual units are usually named after the manufacturer. Conductivity, measured at the DI bottles, reports back to the “Thornton” meters; each of the Thornton modules can handle two conductivity sensors. A PEEK meter (brand name only, not chemical composition) measures flow through the DI bottles, while the other flow meters report to the "Ronan X54."

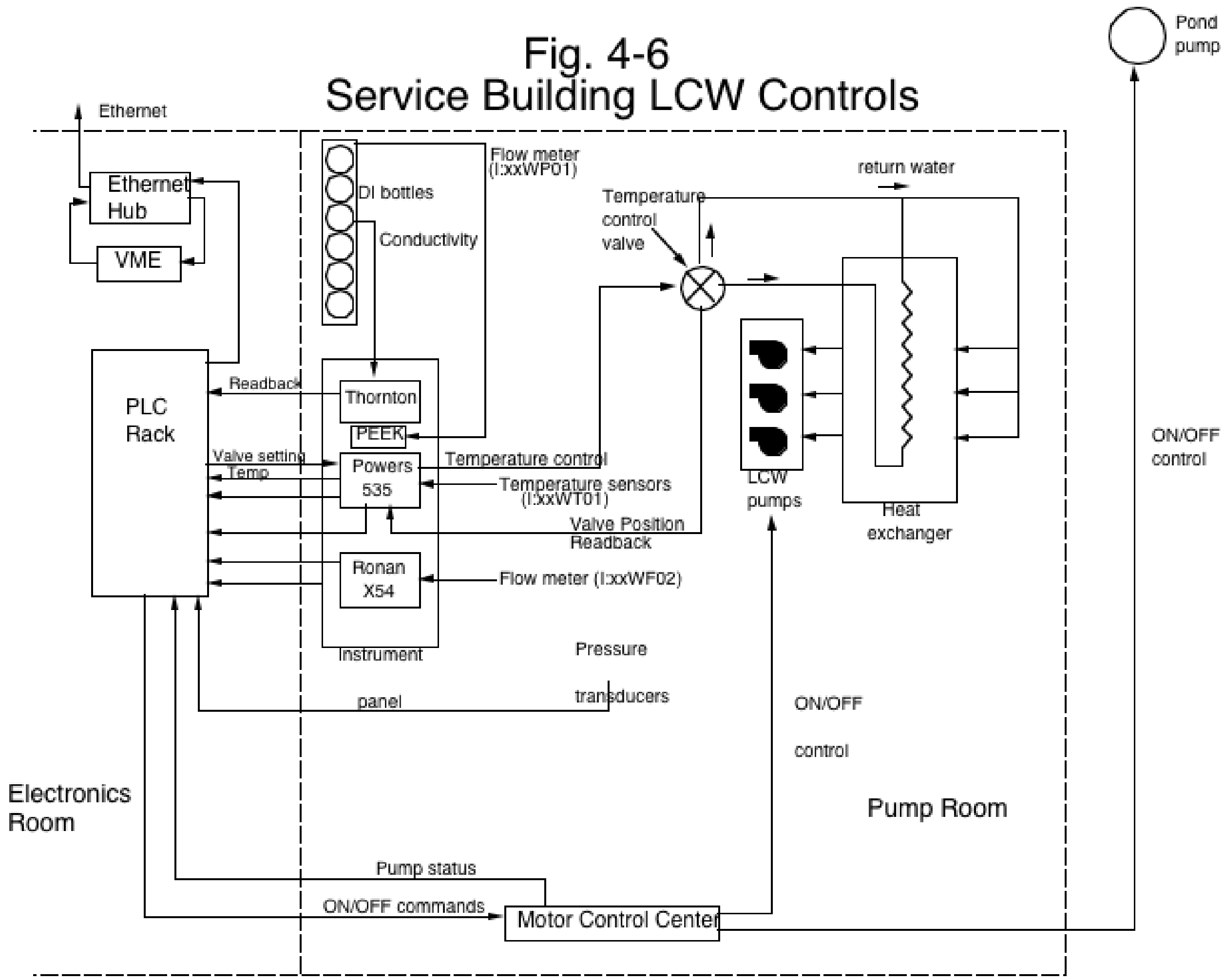


Fig. 4-6
Service Building LCW Controls

The most sophisticated of the modules in the Instrument Panel is the "Powers 535," which handles temperature control. Not only does it read the temperature sensors and the TCV position, it also runs the algorithm that maintains the temperature of the LCW at the desired level by adjusting the TCV.

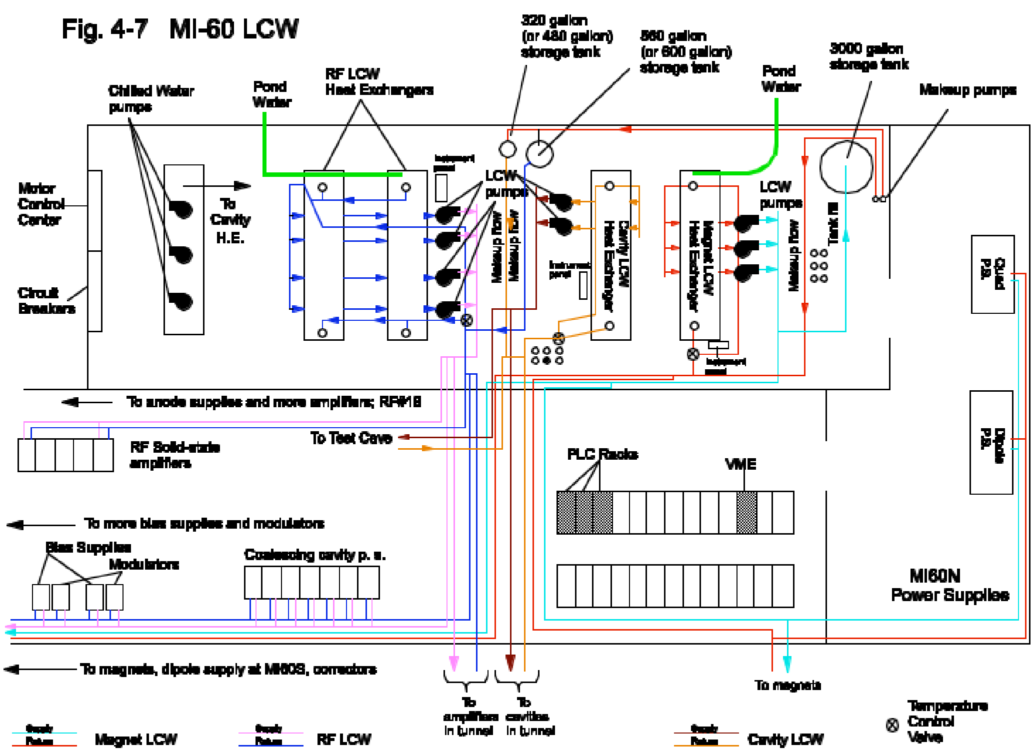
Overseeing the Instrument Panel and other controls functions are the PLCs, or Programmable Logic Controllers. These are Six-trak PLCs, a different type than those used for the power supplies. They are housed in racks in the Electronics Room. Six-trak PLCs, unlike those for the power supplies, are capable of reading analog signals. The PLCs read the analog readbacks for conductivity, temperature, and flow rates from the Instrument Panel; the pressure transducers and pump status from the MCC are read directly by the PLCs. In the other direction, digital control of the pond and LCW pumps is routed through the PLCs.

A VME crate, the same one that consolidates data from the power supply PLCs at the service building, is also the interface between the Six-trak PLCs and the rest of the world. Since this is the Age of Networking, the PLCs and the VME, which are three feet away from each other, must talk to each other through the local Ethernet hub. The VME, after organizing the information, starts the data on its journey toward the Main Control Room via the ring-wide Ethernet. For the rest of the story, read the hypothetical Controls chapter.

Water at MI-60

The LCW systems at MI-60 (Fig. 4-7) are more complicated than those at the service buildings. They not only have to supply water to the magnets, but to the RF systems as well.

Fig. 4-7 MI-60 LCW



This map is believed to be topologically correct, although numerous details have been omitted in a futile attempt to achieve clarity.

All of the systems are gathered together in the Pump Room at the north end of the building. There are actually four distinct water systems in the Pump Room, going from south to north (left to right in Fig. 4-7). They are the Industrial Chilled Water system, the RF system, the Cavity system, and the Magnet system.

Industrial Chilled Water

The Industrial Chilled Water (ICW) is not actually a low conductivity system. It supplies water to the fire sprinkler heads and air conditioners throughout the building. The ICW pumps and pipes are painted red everywhere in the building for quick identification during an emergency. Its importance to the LCW is that it is heat exchanged with the LCW in the Cavity system (see below).

RF System

"RF" here is understood to mean the RF power supplies rather than the cavities themselves. The RF water is divided into three major branches. One branch provides water to the coalescing cavity supplies as well as to the bias supplies and modulators for 17 of the 18 accelerating stations. The second branch, running along the east wall of the building, goes to the solid-state MOSFET amplifiers, the anode supplies, and the bias supply and modulator for the remaining accelerating station (#18). The third branch plunges into the tunnel in order to cool the power amplifiers on top of the cavities.

The RF LCW, which is responsible for cooling a large heat load, requires two heat exchangers and four LCW pumps. Heat is exchanged with pond water as with the other service buildings.

Being a stand-alone system, the RF LCW has its very own 560-gallon storage tank for replacing lost water.

Cavity System

Since the RF cavities represent a relatively small heat load, only one heat exchanger and two LCW pumps are needed. As mentioned above, the Cavity LCW is heat exchanged with the ICW rather than with pond water. The Cavity system, also stand-alone, is provided with a 320-gallon storage tank. In addition to cooling the cavities in the tunnel, there is a branch that feeds the Test Cave area upstairs.

Notice on the diagram that the 320-gallon tank is physically located nearest the RF system, and the 560-gallon tank is located nearest the Cavity system. Both of these storage tanks get their makeup flow from the 3000-gallon tank of the magnet system, to be described next.

Magnet System

The magnet LCW is similar in most respects to the LCW setup at the other service buildings with one heat exchanger and three LCW pumps. Inside the Pump Room, it splits into a north and a south branch. Upon reaching the east wall, each of the two branches splits again, with one secondary branch entering the tunnel to service the magnets and the other going to the main power supplies.

In the tunnel, the branches join the main LCW headers at the upstream and downstream ends of the long straight section. A relatively small crossover supplies the main quadrupoles that are scattered among the cavities. Remember that there are no main dipoles in the straight section, so the heat load is minimal.

What is different about the magnet system at MI-60 is the 3000-gallon storage tank (not to be confused with the 3000-gallon tank at CUB, which has a similar name). Since most of the magnets in the ring are connected to a common header, this tank is used to make up water for the entire ring. The water is added to the suction side because of its lower pressure. The tank, in turn, is filled with LCW from CUB when it runs low. In addition to the magnet system, the 3000-gallon tank at MI-60 is used to fill the storage tanks for the RF and Cavity systems, and the (otherwise) independent system at MI-52.

Nitrogen gas, obtained from bottles, is used to control the head pressure of the 3000-gallon tank. That is, there is nitrogen at the top of the tank exerting a pressure that is transmitted throughout the system; since makeup flow is added to the suction side, the regulated pressure of the nitrogen controls the suction pressure of the water. It is important to keep the suction pressure comfortably above atmospheric pressure in order to keep the pumps from cavitating. Cavitation occurs when the pressure of the system drops below the vapor pressure of the water, and the water begins to boil. The dramatic increase in volume and pressure and the highly energetic “bubbles” bouncing around inside the pipe can cause a great deal of damage. There is a line from the tank to the return header that must be open to maintain continuity of pressure whenever the pumps are running.

There are two small makeup pumps associated with the MI-60 system. They are turned on only when makeup flow is needed. One of the pumps sends makeup water to the Magnet system. The LCW is first pumped through the DI bottles; the flow can then go either to the return line or back to the makeup tank. The other pump sends makeup water to the RF and Cavity systems.

Makeup water is configured more or less the same way for the RF and Cavity systems, and at MI-52.

An advantage of using nitrogen, as opposed to ordinary air, is that oxygen is excluded. The presence of dissolved oxygen in the water would lead to the creation of copper oxides in the magnets and busywork. In other accelerators, copper oxides have had a shameful history of clogging up the plumbing and causing much downtime due to overheated magnets.

Each of the three LCW systems at MI-60 is supported by a technical infrastructure similar to that found at the other the service buildings: Instrument panels, Temperature Control Valves, DI bottles, etc. Three PLC racks and the VME crate are found in the gallery to the east.

CUB

So far in this chapter, the Main Injector LCW systems have been treated as “stand-alone;” that is, as if all of the pumping, cooling, and deionization takes place locally at the service buildings. It is indeed possible to operate all of the Main Injector water systems without outside help, except for occasional makeup flow. However, CUB plays a major role in deionizing the LCW, and is the primary source of makeup water to the ring.

Fig. 4-8 represents the layout of the Central Utility Building. CUB supplies water to much of the accelerator complex; those functions having to do with the Main Injector and the Tevatron are shown in color.

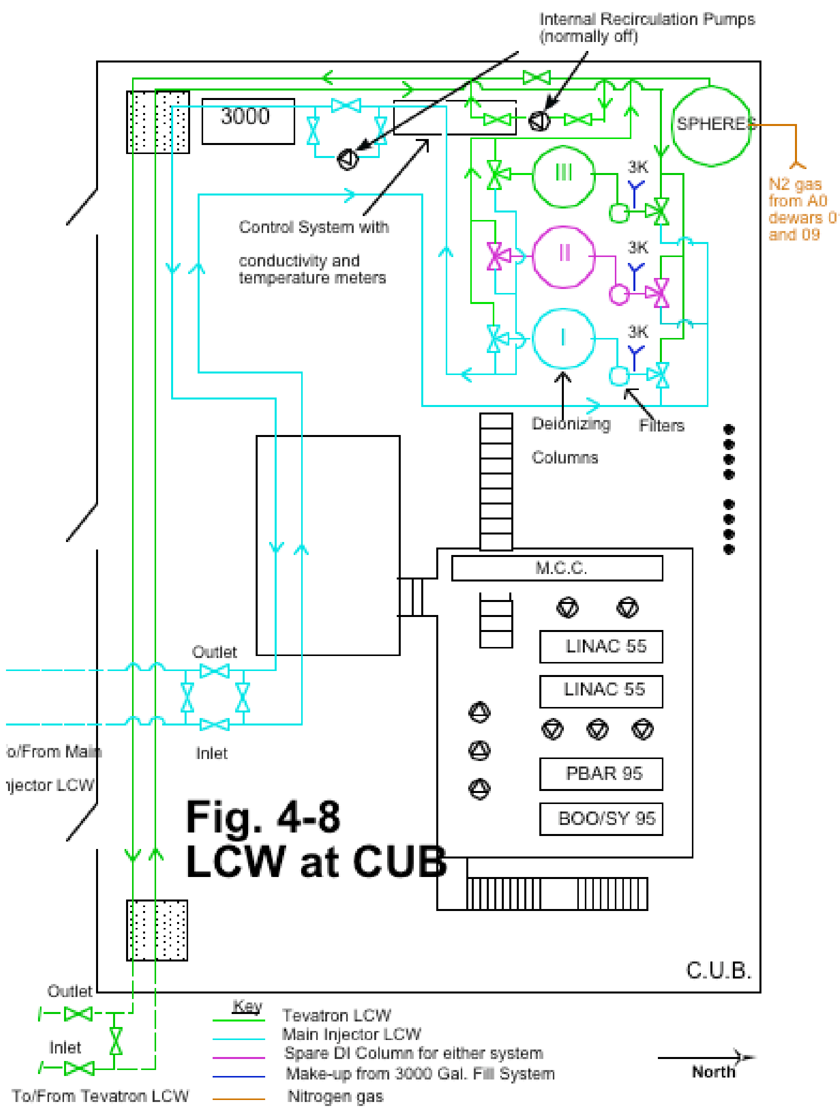


Fig. 4-8
LCW at CUB

The two systems are interrelated and will be considered as a single entity here.

The heart of the system (or perhaps more appropriately, the kidneys) consists of the three large deionizing tanks (or columns) in the northwest corner, labeled I, II, and III. Normally, the Main Injector uses Column I and the Tevatron uses Column III, while Column II can be used as a spare for either. If necessary, the columns can be reconfigured so that any column can cleanse the water from either machine.

The primary reservoir of LCW at CUB for the Main Injector and the Tevatron is contained in the spheres. Certainly among the most unusual water containers on the planet, the three large spheres are stacked vertically in the northwest corner of CUB. Like the magnet storage tank at MI-60, they can hold about 3000 gallons. Also, like the 3000-gallon tank, the head pressure at the top of the spheres is maintained by nitrogen gas at the top of the water. Boiling off some of the liquid nitrogen from the Dewars at A0 derives the nitrogen.

The spheres are the primary source of makeup flow for the Main Injector as well as the Tevatron. Water can also be drawn directly from the 3000 gallon tank at CUB, not to be confused with the other two 3000 gallon systems already discussed.

The supply and return lines to the Main Injector exit CUB from a point near the center of the south wall. Traveling underground, they skirt the Antiproton Source and penetrate the wall of the MI-8 enclosure at location 809 (look again at Fig. 4-3). There is a branch from 837 leading up to the MI-8 building, used for cooling the bulk supplies for the correction elements in the MI-8 line. A small branch from 809 feeds the powered magnets downstream of the shielding wall, but the magnets of the MI-8 line upstream of the wall are cooled separately, from the Booster LCW header originating at Long 4. The powered quads at the end of the MI-8 line are supplied from the same branch that services the quads downstream of the shielding wall.

There are no pumps to force the water back to CUB, so the supply water, which is already at high pressure) is tapped from the header at a point between 640 and 641. However, rather than entering the return line at 640, the water coming back from CUB is diverted to 624. The reason for this is to try to put enough separation between the point of entry and the point of departure. Otherwise, the water might end up looping exclusively between 640 and CUB. The LCW pumps in the service buildings, the flow restrictors, and the makeup flow maintain the overall clockwise flow in the ring at 624.

Entry and exit to CUB is controlled by the inlet and outlet valves, which are normally open. Once inside, the water passes through Column I, and, refreshed and not under so much pressure, starts back to the Main Injector ring.

Sometimes, especially when the columns need to be regenerated, closing the inlet and outlet valves and opening the bypass valve can set up a pattern of internal circulation. The setup is similar for both the Main Injector and the Tevatron. A small pump, used only for internal circulation, can be used to maintain flow through the columns.

If water needs to be made up and CUB is down, domestic water can be used. Domestic water is the "ordinary" water used site wide for bathrooms and drinking fountains, and of course is of insufficient purity to use in the magnets. The water, drawn from the domestic line at MI-60, is heavily filtered before being allowed to join the LCW; one of the "filters" is UV light, intended to destroy bacteria that could potentially eat through the stainless steel pipes. Domestic water is also drawn at CUB during normal operations, and processed in a similar way.

Parameter Names

The LCW parameters can be found on I58. Of course, all Main Injector parameter names are of the type I:xxxxxx. On I58, each "character place" is more or less standardized to represent some particular facet of the LCW.

Going from left to right:

- The first two characters give the location of the device: “10” for MI-10, etc. At MI-60, “60” is assigned to the magnet system, “6R” to the RF system, and “6C” to the Cavity system.
- The third character in an LCW parameter name is usually “W,” for “water”.
- The fourth character describes the type of device; for example, “L” means “liquid level,” e.g. I:60WL01 refers to the water level in the 3000 gallon storage tank for the magnet system at MI-60, and I:6RWL01 refers to the liquid level in the 560 gallon storage tank for the RF system. “V” stands for valve, “P” for pressure, “F” for flow, “T” for temperature, and “R” for resistivity. For digital control parameters of the pumps, such as I:60WS01, the “S” stands for “start,” or, I suppose, “stop.”
- The last two digits in an LCW parameter name are numeric, specifying which device of a particular type is meant. A serious attempt has been made to ensure that diagrams, parameter names, and labels on the equipment all correlate with one another.

By themselves, the parameter names and descriptor text often do not reveal much about the specific functions of the devices that they represent. However, the names and numbers are standardized from building to building (except for MI-60), and most functionality can be determined from the graphics called up from I56. At MI-60, the three systems are more complicated than the rest—primarily because of the storage tanks and associated makeup flow—and the conventions used at the other service buildings are largely abandoned.

Specific parameter naming schemes for the major service buildings MI-10 through MI-50 are described below, along with some of the ways that parameters can be interpreted and used; MI-60 parameters are unique enough to require a separate discussion. Since the first two characters in an

LCW parameter usually refer to the service building or RF system, and since the third character is usually "W," names in the following section will frequently be abbreviated to the last three characters.

Pumps

"S", as mentioned earlier, designates pumps. I:xxWS01, S02, and S03 display the digital status of the three LCW pumps at most service buildings; all three pumps are normally on. S04 and S05 represent the pond pumps; one of the pumps is usually on. A sixth pump parameter, I:xxWPND, is the "Pond Pump Digital Status."

The pumps can also be controlled through these parameters, although other applications (such as I56) are used more frequently.

In the MI-60 Magnet system, the LCW pumps are still named I:60WS01, S02, and S03, but S04 and S05 refer to the two small makeup pumps next to the 3000 gallon storage tank. The pond pumps are designated S06 and S07.

The RF system at MI-60, because of the large heat load, requires two heat exchangers and four LCW pumps. The pumps are designated I:6RWS01, S02, S03, and S04. There is one pump for handling makeup flow, designated S05, and two pond pumps named S06 and S07.

In the Cavity system, I:6CWS01 is the makeup pump. S02 and S03 are the LCW pumps. There are no pond pumps as such, since the LCW heat exchanges with the ICW.

Valves

In non-MI-60 buildings, V01 and V03 represent the valves on the supply headers as they enter the tunnel; V02 and V04 are the valves on the return headers. These four parameters are digital readbacks, showing whether the valves are open or closed.

I:xxWW01 is the position of the TCV, measured in "% open." The percentage refers to the amount of return water sent through the heat exchanger.

In the MI-60 Magnet system, V01 and V02 refer to valves upstream of the makeup pumps S04 and S05, respectively. V03 is a valve on the makeup line that adds water to the return line, near the TCV. V04 is on the line that connects the supply header to the DI bottles. The TCV is designated I:60WW03.

In the RF system, there are six valves related to handling the flow of makeup water. The 560 gallon tank supplies much of the makeup water to the system, but that tank, in turn, gets its water from the 3000 gallon tank of the MI-60 Magnet system.

V01 opens to let water from the 560-gallon tank flow to the DI bottles.

V02 is the gate (water-gate) that allows water to come in from the 3000-gallon flow line. If V03 is open, the makeup water flows into the 560-gallon storage tank, and if V04 is open, the water goes directly to the DI bottles.

V05 and V06 are valves in the DI loop. V05 is in the supply line and V06 is in the return line.

In the Cavity system, I:6CWV01 is on the makeup line from CUB; V04 lets the makeup water into the storage tank. V02 isolates the storage tank from the makeup pump, and V03 lets the water from the 3000-gallon tank enter the Cavity system on the supply side of the DI loop. V05 is on the supply side of the DI circuit, and V06 is on the return line of the circuit. Since V06 can isolate the storage tank from the return line, it should normally be left open, otherwise the return header will not feel the head pressure from the storage tank.

Flow Readbacks

Flow readbacks are given in gallons per minute (GPM).

I:xxWF01, “DI processing,” measures the amount of flow going through the DI bottles. This is the value read at the PEEK meter on the Instrument Panel.

I:xxWF02, “Gallery Supply,” is the total amount of flow going to the magnet strings in the tunnel. The PLCs use F02 to monitor the flow and shut off the LCW pumps if it exceeds certain limits. If the upper limit is exceeded it is likely that there is a major leak downstairs, and one might as well not send lots of pressurized water in that direction. The upper and lower limits are set through the parameters I:xxWF2U and I:xxWF2L. The flow meter hardware can be found hanging from the supply header at the entrance to the corridor leading to the tunnel.

In the MI-60 Magnet system, F01 measures flow into the 3000 gallon storage tank; F02 is the flow out of the DI bottles; F03 and F04 measure flow to the two branches of the supply headers as they go into the tunnel. Trip limits (I:60WF3L, etc.) can be set for F03 and F04.

In the RF system, I:6RWF01 measures the flow coming into the RF system from the 3000-gallon tank. F02 reads the flow going from the DI bottles into the 560-gallon tank, and F03 reads the amount of flow from the DI bottles to the return header (i.e. the water actually being added to the system). F04 measures the total amount of flow headed for the solid-state MOSFET amplifiers and the anode supplies. F05 represents the flow to the modulators, bias supplies, and coalescing supplies in the gallery; F06 reads the flow to the amplifiers in the tunnel.

In the Cavity system, F01 measures makeup flow from the 3000-gallon tank, F02 is the flow from the DI bottles to the 320-gallon (Cavity) storage tank, and F03 is the flow from the DI tanks to the return header. F04 is flow in the supply line leading to the Test Cave, while F05 is flow in the supply line to the cavities in the tunnel.

Pressure Readbacks

Remember that discharge pressure is read from the output side of the pump, while suction pressure is read from the input side. (Discharge is the same as supply pressure and suction is the same as return pressure.) Of course, if a pump is on and working properly, the discharge pressure will be significantly higher than the suction pressure.

As mentioned earlier, pressure gauges are read directly by the PLCs, and do not go through the Instrument Panel.

I:xxWP01 represents the pressure of the LCW return from the tunnel, measured just upstream of the TCV.

P02 is the pressure in the supply header, before it branches and enters the tunnel.

P03, P04, and P05 measure the discharge pressure from the three LCW pumps S01, S02, and S03 respectively. P06, P07, and P08 represent the suction pressure for those same pumps. The PLCs monitor upper and lower limits on the suction pressure, which are set through the parameters I:xxWP6U, 6L, 7U, 7L, 8U, and 8L. If the suction pressure is too low, the pumps will cavitate, and the PLCs will shut them down.

P09 is the pressure of the pond water at the inlet to the pond pumps, and P10 is the output pressure.

P11 is the water pressure in the DI line, measured between the regulator and the bottles.

The MI-60 Magnet system has about 30 pressure gauges.

P01 measures pressure on the makeup line leading to the RF and Cavity systems. There is no P02 or P03.

P04 is the pressure of the pond water as it leaves the heat exchanger. P05 is the pressure of the LCW as it leaves the heat exchanger. P06 is at the pond strainer outlet, and P07 is at the pond strainer inlet.

The next block of pressure gauges, from P08 to P16, is dedicated to the LCW pumps. LCW pumps in the Magnet system are equipped with 3 pressure gauges, on the suction side there is one at the strainer inlet; the second, “suction pressure,” is at the inlet of the pump. The difference between the two represents the pressure drop across the strainer. The third is on the discharge side. The pumps are interlocked to the suction pressures.

P17 is the pressure of the LCW as it leaves the heat exchanger. P18 measures the water pressure in the outlet line from the 3000-gallon tank, and P19 measures the head pressure inside the tank. P20 measures the discharge pressure from S05 (the makeup pump to the RF and Cavity systems) and P21 does the same for S04 (the makeup pump for the Main Injector ring). P23 measures the pressure of the LCW going into the 3000-gallon tank. P24 reads the pressure coming out of the DI bottles, and P25 measures it coming out. P26 is at the check valve downstream of the DI bottles; P27 is at the strainer.

On the lines running to the magnets and power supplies, P30 and P31 monitor supply and return pressures on the south branch , while P32 and P33 monitor the south branch.

The RF system also has numerous pressure readbacks. The first ten (numerically) monitor the pond pumps and heat exchangers. There is a strainer for the pond water coming in to the heat exchangers; it is bracketed by P04 upstream and P01 downstream. A significant pressure drop across the strainer might indicate that it is getting clogged. P05 reads the pressure of the pond water entering Heat Exchanger #1 and P07 reads it as it leaves. P08 and P10 do the same for Heat Exchanger #2. P03 reads the pressure after the two lines have merged, as the water enters the sprayer of the pond.

P06 and P09 read the pressures of the LCW coming out of the two heat exchangers. Jumping ahead (numerically), P23 and P24 measure the pressure of the LCW going into the heat exchangers.

The block of gauges from P11 to P22 monitors the pressures at the four LCW pumps. Each pump has three gauges. P11, P14, P17, and P20 are “pre-valve” readings, the manually operated valve being underneath the heat exchangers. P12, P15, P18, and P21 monitor the suction. P13, P16, P19, and P22 measure the pressure in the discharge lines.

The many ways that LCW can be moved around the DI bottles and storage tanks can be appreciated by sampling the related pressure gauges. P25 measures the pressure on the output branch of the 560-gallon tank that empties into the return header, adding to the volume of water that is circulating among the components. P27 reads the head pressure inside the 520-gallon tank. P28 measures the pressure on the return side of the DI loop, and P29 measures it on the supply side, upstream of the regulator. P31 is read downstream of the regulator, and also downstream of the point at which flow merges with any makeup flow. The readback for P32 is taken at the outlet of the DI bottles.

Of course, all of this water has to be used somewhere. P36, and P34 further downstream, measure the pressure of the supply header servicing the solid-state amplifiers and the anode supplies in the gallery. P33 and P35 read the pressure on the associated return header. P41, and P38 further downstream, measure the supply pressure to the bias supplies, modulators, and coalescing cavity supplies; P39 and P37 read return pressures. P42 measures the supply pressure to the amplifiers in the tunnel and P40 measures the return pressure.

Exploration of the pressure gauges in the Cavity system is left as an exercise for the reader, because this is becoming way too tedious for the author. The Cavity system is actually considerably simpler than the RF system. The important differences to remember are that pressures are measured on the ICW system rather than pond pumps, and that there is a branch leading to the Test Cave.

Resistivity

On a parameter page, resistivity is measured in units of “Megohms,” by which is really meant Megohms per centimeter.

There are three critical measurement locations at a typical service building. I:xxR01 measures resistivity in the return line from the tunnel. It is here that resistivity is likely to be at its worst, because the water has had a chance to pick up dissolved material as it moves through the headers and magnets. R02 measures the resistivity going into the DI bottles, and R03 measures it coming out. A comparison of R02 and R03 is a measure of how effectively the DI bottles are working.

In the MI-60 Magnet system, I:60WR01 is measured as it leaves the 3000 gallon storage tank; R02 is read as LCW is being diverted from the supply header toward the DI bottles, upstream of the DI filters; R03 is downstream of the DI filters; and R04 samples the resistivity on the return line just upstream of the TCV (i.e. it is the equivalent of R01 in the other service buildings.

In the RF system, I:6RWR01 is the resistivity coming out of the 560-gallon storage tank; R02 is at the inlet to the DI bottles; R03 is at the outlet of the DI bottles; and R04 is on the return line just upstream of the TCV. In other words, the naming convention is the same as that in the Magnet system.

In the Cavity system, I:6CWR01 is the resistivity of the LCW coming out of the 320-gallon storage tank; R02 measures the return water after being scrubbed in the DI bottles; R03 is supply water on its way to the DI bottles, and R04 is water returning from the tunnel or the Test Cave. In other words, the naming convention for R02 and R03 has been reversed from that of the Magnet and RF systems.

Temperature

Since Fermilab is the world's leading institution for the study of the fundamental nature of matter and energy, temperature is measured using the Fahrenheit scale.

I:xxWT01 is the temperature of the LCW in the supply header before it encounters the magnets, power supplies, or DI bottles. At T01 the water has not passed through any heat loads, so the reading at that location can be interpreted as a measure of the overall health of the heat exchange process. T01 is therefore used as the set point controlling the position of the TCV, which regulates the amount of water going to the heat exchanger. If T01 is too high, the TCV sends more water through the exchanger, and vice-versa. Being a controllable parameter, typing in a new D/A value can change the set point, but it is usually set near 90˚.

The PLCs also use T01 as an interlock to protect the magnets from undue thermal stress. The readback is approximately the temperature that the magnets will see. The main threat is to the epoxy and insulation surrounding the magnet coils; too cold and it may become brittle and shatter, or too warm and it could become soft and melt. Either extreme could compromise the integrity of the coils. The upper and lower limits are set through the parameters I:xxWT1U and I:xxWT1L. Typical limits are 40˚F for the lower limit and 150˚ for the upper limit. If the limits are exceeded, the LCW pumps at the service building trip off.

T02 is the temperature of the water going into the heat exchanger, while T03 is the temperature coming out. Comparing the two is a measure of how effectively the heat exchanger is performing. For example, on a hot day the pond water may be too warm to allow the heat from the LCW to be dissipated efficiently, and T02 and T03 will not differ by much.

The return flow, of course, is divided between that which flows through the heat exchanger and that which doesn't. T04 looks at the temperature of the water after the two branches have merged, and is a measure of the LCW temperature just upstream of the pumps.

At the MI-60 Magnet system, T01 measures the temperature of the pond water as it emerges from the heat exchanger; T02 is the temperature of the LCW at the inlet of the heat exchanger; T03 is the pond water temperature as it enters the heat exchanger; and T05 is the LCW temperature after the water has been cooled by the heat exchanger.

T04 measures the temperature of the supply water before it goes into the magnets in the tunnel. It performs the same function as T01 does at the other service buildings, providing feedback to the TCV for temperature regulation and protecting the magnets from temperature extremes. The low trip limit for T04 is set from I:60WT4L, and the high trip limit is set through I:60WT4H.

In the RF system, there are two heat exchangers, but the temperature readbacks monitor lines that are common to both. T01 is just upstream of the pumps, as they pull water out of the exchangers and into the pond. T03 measures the temperature of the LCW as it leaves the heat exchangers and T04 measures it as it is going in.

T05 measures the temperature of the water in the supply header before it goes to the power supplies and amplifiers. This reading provides feedback for the TCV.

In the Cavity system, I:6CWT01 measures the temperature of the supply water headed toward the cavities or the test cave; the reader can probably guess that it is used in the feedback for the TCV. T02 and T03 monitor the ICW temperature going in to and out of the heat exchanger, respectively. T04 measures the return water temperature, just downstream of the TCV, as it enters the heat exchanger.

Liquid Level Readbacks

The storage tanks for the various LCW systems are at MI-60, MI-52, and CUB. There are two types of parameters for reading the amount of water in the tank. One of the parameters displays the water level of the tank in inches, which is the way that the instrumentation hardware actually sees it.

The second parameter uses a scale factor to convert the value to gallons, which is intuitively easier for the user.

In the MI-60 magnet system, I:60WL01 represents the height of the water column of the 3000-gallon tank in inches. I:60WVOL converts inches into gallons. A trip indication is generated if the liquid level is out of bounds. I:60WL1L is the lower trip limit, I:60WL1H is the high trip limit, and I:60WL1I is the “low inner trip limit.”

The liquid level in the 560-gallon tank of the RF system is read from I:6RWL01; for the 380-gallon tank, it is I:6CWL01, and at MI-52, it is I:52WL01. None of these storage tanks have corresponding parameters for volume.

The “leak” parameters work by measuring the change in the makeup tank levels. In the MI-60 Magnet system, I:LEAK is the almost real-time leak rate, averaging the rate over the previous minute. I:LEAKF (fast leak) is averaged over the previous 5 minutes, and I:LEAKS (slow leak) over the previous ten minutes. Equivalent parameters exist for the RF and Cavity systems (e.g. I:RLEAK, I:CLEAK). A negative leak value means that the tank is being filled.

There is a special measure of makeup flow to the RF and Cavity systems known as the TOTalizer, donated by the Arnold Schwarzenegger Foundation. Makeup flow to the RF system is I:6RWTOT, and makeup flow to the Cavity system is I:6CWTOT. The TOTalizer integrates the amount of makeup water transferred to those systems over a period of time (say, midnight to midnight). If the amount is excessive, as with a leak, an alarm is generated.

Vibration Sensors

These are named I:xxWUxx, where the first two characters designate the house number and the last two numbers correlate to the pump number. The vibrations are measured in Hz. At the time of this writing, none of these devices have actually been implemented, but parameters can be found on some pages.

CUB Parameters

The most important CUB parameters to know might be:

- T:CWVOL, which is the volume of the LCW in the spheres, measured in gallons.
- T:CWL01, the height of the LCW in the spheres, measured in inches. Being spheres, you might want to revert to T:CWVOL if you want to know how much water you have, unless you really like geometry problems.
- I:CWR101, which measures the resistivity coming out of Column I (the column normally used for Main Injector).
- I:CWV28 and I:CWV29, which are the outlet and inlet valves (respectively) to CUB from the Main Injector.
- I:CWV22, makeup water to the spheres.
- I:CWV419 and I:CWS03. When the pump S03 is running and the valve V419 is open, makeup water is pumped from the spheres to Column I, eventually to make its way back to the Main Injector.

Pump Interlocks

Much of the information in this section has already been covered in this chapter, but this section consolidates material relevant to the interlocks.

Traditionally, status for the RF water systems in the Main Ring was monitored through FIRUS. For some reason unknown to the author, this tradition has been extended to include the Main Injector. There are analog readbacks through ACNET, but there are no PLC trip limits or trip flags read through ACNET, nor is there any digital control of the pumps or valves. (On I25, there is the Watchdog trip, which inhibits the RF drive if the RF system conductivity or temperature limits are exceeded, but the pumps are not affected.) The discussion below does not include the RF or Cavity systems.

The trip limits alluded to in the description of parameter names are usually enforced through interlocks to the pump motors. A temperature, pressure, or flow rate that is out of bounds will cause the pumps at to trip off. The trip limits can be modified from Page I56 or from a parameter page.

Trips can be global, or restricted to a particular house or even a single pump, depending on what is being protected. Global trips turn off all of the pumps ring-wide (except for the independent systems such as at MI-52). They include:

- I:60WL01, the liquid level in the 3000 gallon tank, and
- I:60WV03, which connects the tank to the return header. Remember that V03 needs to be open in order to maintain the suction pressure.

House trips shut off all of the pumps at a given service building. They include:

- F02, the flow rate in the supply header going to the magnets,
- T01, the temperature of the water going to the magnets, and
- V14, which is actually a summation of V01 through V04, the valves on the supply and return lines just before they enter the tunnel.

The equivalent parameters for the magnet system at MI-60 are:

- F34, which is the summation of F03 and F04;
- T04 (which has the same function as T01 at the other houses), and
- There is a house trip if both pond pumps trip off. More about that below.

Single pump trips are generated whenever the return pressure (P06, P07 or P08) strays out of limits. The pump is turned off primarily to prevent cavitation. When a single pump trips, a possible consequence is that the local power supplies will also trip.

The LCW pumps are also interlocked to the pond pumps. Normally, only one of the two pond pumps needs to be running at each house. If the one pump trips off, the other is automatically turned on. In order to give the second pond pump time to turn on, there is a 15-second delay before the LCW pumps respond to a trip. A failure of both pond pumps causes a house trip of the LCW pumps, so that hot water is not pumped to the magnets.

At MI-10 through MI-50, the pond pumps are designated S04 and S05, so the interlock summation is S45. For the MI-60 Magnet system, pumps S06 and S07 are summed into S67. Pond pumps are interlocked to high temperature, not to the water, but to a temperature sensor internal to the motor. They are also interlocked to their own output pressure (P10), and to the differential pressure across the pump.

Turning on Pumps

On Page I56, on the “Global” sub page, there is an “Auto-on” option that performs the necessary steps to turn on the LCW pumps ring-wide. (As of this writing, there is no option for turning on the pond pumps globally.) This is what it does:

- Sends a reset to all of the trip flags. This checks that the pond pumps are on and the inlet and outlet valves to each building are open. Some of the trip flags, such as flows and pressures, will have bad status because the pumps are off. To avoid a viscous circle, there is a delay of 15 seconds before those trips re-assert themselves in order to give the pumps time to turn on.
- V03 and V04, the DI loop valves in the magnet system, are opened. Remember that it is these valves, especially V03, which maintain the proper pressures in the ring.
- Pumps 1 and 2 at each house are turned on.

- After several seconds, Pump 3 at each house is turned on.

The MI-52 system does not yet have an automatic startup sequence. To turn on the pumps manually, a similar sequence is followed.

PLC Logic

The turn-on sequence, of course, is controlled by the PLCs. The PLCs progress through a series of operational states, as shown in Fig. 4-9.

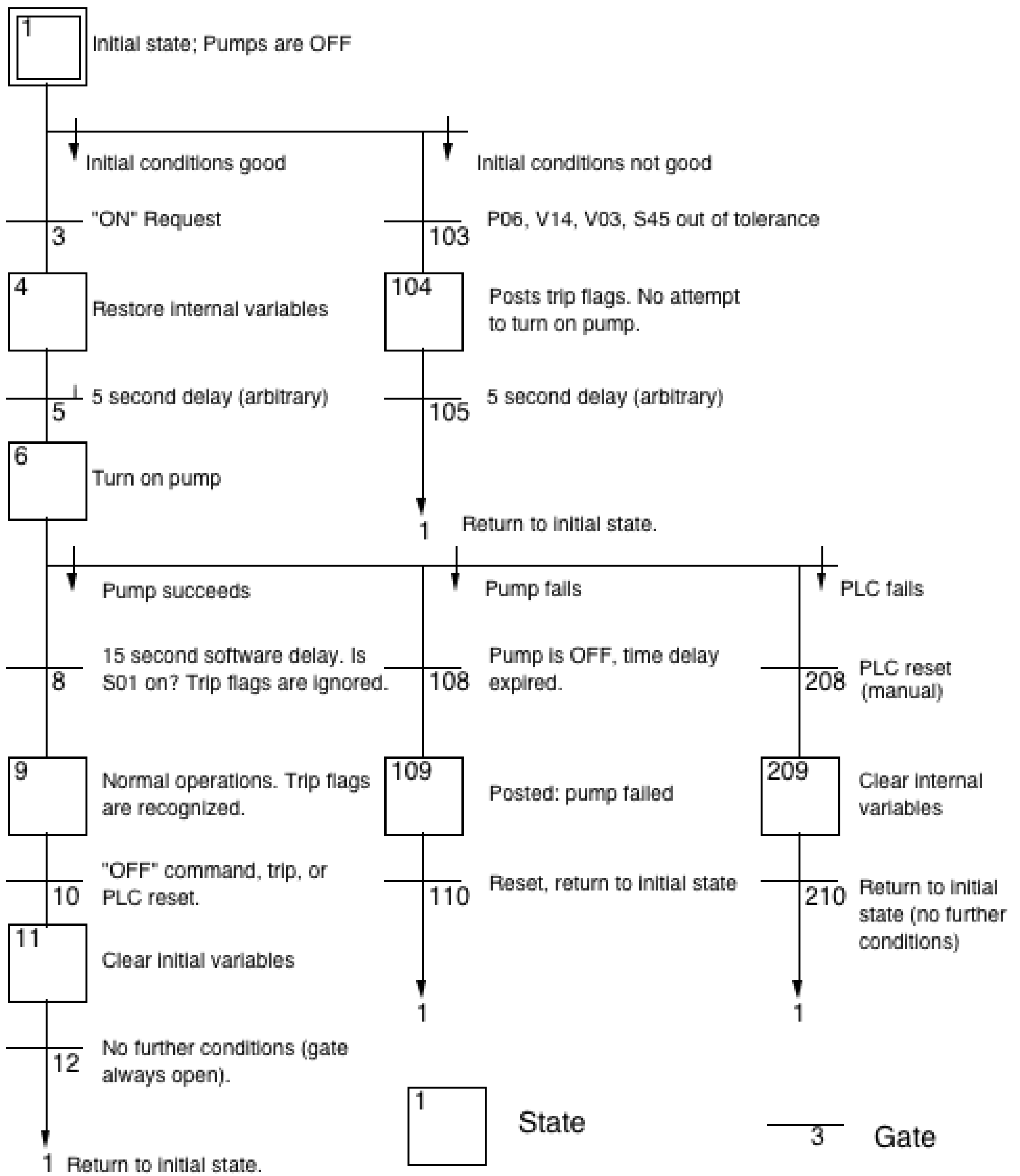


Fig. 4-9 Typical PLC State Logic for LCW pump

The PLC state is usually read from I56, where states 1, 2, and 3 refer to the LCW pump number. The operational state can also be read as a parameter, for example, I:10WST1 represents LCW Pump #1 at MI10.

In Fig. 4-9, the boxes represent operational states, while the horizontal lines are gates leading to the next state. A successful sequence would begin at State 1 (the initialized state) and, passing through Gate 8, ends at State 9. If the machine is operational, most of the pumps are in State 9. If an “off” command is sent, or a trip detected, the logic continues through State 11 and returns to State 1. The same is true of a PLC reset, which reinitializes the logic and shuts the pump off.

If the pump fails to come on during the 15-second delay at Gate 8, it passes instead through Gate 108 and ends up in State 109. Usually pumps that are off are in State 109.

If an “on” command is sent, but the suction pressure, inlet and outlet valves, or pond pumps are not in the proper state, the logic is routed through Gate 103 and back to the initial state. No attempt is made to turn the pump on.

This chapter has been about filling pipes with water. The next, “Vacuum,” will be about how to keep pipes empty.